

more dispersion prisms may be used, wherein the grating would produce a relatively higher degree of dispersion than the prisms although generally exhibiting somewhat lower efficiency than the dispersion prism or prisms, for a narrow band laser such as is used with a refractive or catadioptric optical lithography imaging system. As mentioned above, the front optics module may include line-narrowing optics such as may be described in any of the 09/715,803, 09/738,849, and 09/718,809 applications, each being assigned to the same assignee and hereby incorporated by reference.

Instead of having a retro-reflective grating in the rear optics module 110, the grating may be replaced with a highly reflective mirror, and a lower degree of dispersion may be produced by a dispersive prism, or a beam expander and an interferometric device such as an etalon or device having non-planar opposed plates may be used for line-selection and narrowing, or alternatively no line-narrowing or line-selection may be performed in the rear optics module 110. In the case of using an all-reflective imaging system, the laser may be configured for semi-narrow band operation such as having an output beam linewidth in excess of 0.5 pm, depending on the characteristic broadband bandwidth of the laser, such that additional line-narrowing of the selected line would not be used, either provided by optics or by reducing the total pressure in the laser tube.

The beam expander of the above exemplary line-narrowing optics of the optics module 110 preferably includes one or more prisms. The beam expander may include other beam expanding optics such as a lens assembly or a converging/diverging lens pair. The grating or a highly reflective mirror is preferably rotatable so that the wavelengths reflected into the acceptance angle of the resonator can be selected or tuned. Alternatively, the grating, or other optic or optics, or the entire line-narrowing module may be pressure tuned, such as is set forth in the 09/771,366 application and the 6,154,470 patent, each of which is assigned to the same assignee and is hereby incorporated by reference. The grating may be used both for dispersing the beam for achieving narrow bandwidths and also preferably for retroreflecting the beam back toward the laser tube. Alternatively, a highly reflective mirror

is positioned after the grating which receives a reflection from the grating and reflects the beam back toward the grating in a Littman configuration, or the grating may be a transmission grating. One or more dispersive prisms may also be used, and more than one etalon or other interferometric device may be used.

Depending on the type and extent of line-narrowing and/or selection and tuning that is desired, and the particular laser that the line-narrowing optics are to be installed into, there are many alternative optical configurations that may be used. For this purpose, those shown in U.S. patents no. 4,399,540, 4,905,243, 5,226,050, 5,559,816, 5,659,419, 5,663,973, 5,761,236, 6,081,542, 6,061,382, 6,154,470, 5,946,337, 5,095,492, 5,684,822, 5,835,520, 5,852,627, 5,856,991, 5,898,725, 5,901,163, 5,917,849, 5,970,082, 5,404,366, 4,975,919, 5,142,543, 5,596,596, 5,802,094, 4,856,018, 5,970,082, 5,978,409, 5,999,318, 5,150,370 and 4,829,536, and German patent DE 298 22 090.3, and any of the patent applications mentioned above and below herein, may be consulted to obtain a line-narrowing configuration that may be used with a preferred laser system herein, and each of these patent references is each hereby incorporated by reference into the present application.

ADDITIONAL LASER SYSTEM FEATURES

Optics module 112 preferably includes means for outcoupling the beam 120, such as a partially reflective resonator reflector. The beam 120 may be otherwise outcoupled such as by an intra-resonator beam splitter or partially reflecting surface of another optical element, and the optics module 112 would in this case include a highly reflective mirror. The optics control module 114 preferably controls the optics modules 110 and 112 such as by receiving and interpreting signals from the processor 116, and initiating realignment, gas pressure adjustments in the modules 110, 112, or reconfiguration procedures (see the '353, '695, '277, '554, and '527 applications mentioned above).

The halogen concentration in the gas mixture is maintained constant during laser operation by gas replenishment actions by replenishing the amount of halogen in the laser tube for the preferred excimer or molecular fluorine laser herein, such that these gases are maintained in a same predetermined ratio as are in the laser tube 102 following a new fill procedure. In addition, gas injection actions such as μ HIs as understood from the '882 application, mentioned above, may be advantageously modified into micro gas replacement procedures, such that the increase in energy of the output laser beam may be compensated by reducing the total pressure. In addition, the laser system is preferably configured for controlling the input driving voltage so that the energy of the output beam is at the predetermined desired energy. The driving voltage is preferably maintained within a small range around HV_{opt} , while the gas procedure operates to replenish the gases and maintain the average pulse energy or energy dose, such as by controlling an output rate of change of the gas mixture or a rate of gas flow through the laser tube 102. Advantageously, the gas procedures set forth herein permit the laser system to operate within a very small range around HV_{opt} , while still achieving average pulse energy control and gas replenishment, and increasing the gas mixture lifetime or time between new fills (see U.S. patent application no. 09/780,120, which is assigned to the same assignee as the present application and is hereby incorporated by reference).

In all of the above and below embodiments, the material used for any dispersive prisms, the prisms of any beam expanders, etalons or other interferometric devices, laser windows and the outcoupler is preferably one that is highly transparent at excimer or molecular fluorine laser wavelengths such as 248 nm for the KrF laser, 193 nm for the ArF laser and 157 nm for the F_2 laser. The materials are also capable of withstanding long-term exposure to ultraviolet light with minimal degradation effects. Examples of such materials are CaF_2 , MgF_2 , BaF_2 , LiF and SrF_2 , and in some cases fluorine-doped quartz may be used, and for the KrF laser, fused silica may be used. Also, in all of the embodiments, many optical surfaces, particularly those of the prisms, may or may not have an anti-reflective coating on one or more